MACHINES FOR MAKING ICE,

USING

SULPHUROUS ACID OR AMMONIA

IN THE PROCESS.

Note from the Establishment of RAOUL, PICTET & CO., PARIS.

Translated by ROBT. BRIGGS, C. E.

REPRINTED FROM THE

JOURNAL OF THE FRANKLIN INSTITUTE,

For February, 1879.

PHIDADELPHIA:

MERRIHEW & SON, PRINTERS, 135 NORTH THIRD STREET.

1879.

[Reprinted from the JOURNAL OF THE FRANKLIN INSTITUTE, February, 1879.]

MACHINES FOR MAKING ICE,

USING SULPHUROUS ACID OR AMMONIA IN THE PROCESS.

NOTE FROM THE ESTABLISHMENT OF RAOUL, PICTET & CO., PARIS.

TRANSLATED* BY ROBT. BRIGGS, C. E.

The result accomplished by a machine in making ice and its corresponding expenditure of force can be investigated as follows:

In order to ascertain with exactness the useful effect of a freezing machine it is needful first to establish the theoretic maximum effect which it can produce, and then make a comparison of ideal result with what may be derived in practice.

[The difference between the theoretic and experimental results will represent the losses incident to the mechanisms employed and to the process followed; being in one case loss of power from friction of parts or of heat from radiation from the apparatus, and in the other the heat expended and transmitted over and above that absolutely demanded for mechanical effect or required to be removed for refrigeration. These losses are grouped in the original under the appellation of "passive efforts."]

* The paragraphs in [brackets] are amendments or additions to the original.

1st. When making ice by any process whatever, it is indispensable to take up the quantity of heat which is set free by the congelation of water, and to carry that quantity of heat to water having the temperature of the surrounding air, which temperature is always above the point of freezing, and generally varies between $+ 10°$ and $+ 30°$ centigrade.

[Throughout this translation metric values for temperatures and quantities of all kinds will be used.]

2d. The mechanical theory of heat furnishes a general formula, which expresses the maximum of labor to be expended in obtaining this result. Calling $q =$ a certain quantity of heat which is made to pass from the lower temperature $= t$ to a higher one $= t'$, and calling $J =$ the mechanical equivalent of heat, equal to 431 kilogram-metres, we have:

$$q \frac{t'-t}{274° + t} J = \text{labor necessary.}$$

[This formula may be elucidated in the following way. The physical phenomenon on which all the machines for ice making is based is the relation of the sensible heat of gaseous bodies to their densities. A gas, having a sensible temperature below the freezing point of water, is permitted to take up a certain quantity of heat of refrigeration of water. It is then compressed by mechanical force until it shall have attained some given temperature above that of a water supply at the disposal of the apparatus, the water from which shall now take up and carry off the quantity of heat originally imparted to the gas, when the gas being permitted to expand (and in a perfect apparatus to give out its force of expansion to the machine) to its original density, it will be prepared to receive another charge of heat, and the complete cycle of operation will have been established.

Let Q be the quantity of heat present in a definite volume of the transfer medium—the gas—at the time when it is in condition to absorb the heat of congelation; let q be the quantity of heat imparted to the transfer medium by the congelation; then $Q + q =$ quantity of heat in transfer medium at some definite condition of energy, and sensible temperature $= t$ which is to be elevated by mechanical effort to t' for the purpose of allowing q to pass off. Let the weight of the medium employed $= W$; then W, multiplied by the absolute temperature of the medium, at any sensible temperature whatever, represents the quantity of heat present at that temperature.

$$\therefore \quad W \times (274° + t) = Q + q \text{ at the temperature } t. \qquad (1)$$

$$W \times (274° + t') = Q + q + H \quad \text{“} \quad t'. \qquad (2)$$

where $H =$ the increment of heat in passing from t to t'.

$$\therefore \quad H = W[(274° + t') - (274° + t)] = W(t' - t)$$

and as from (1) $W = \frac{Q+q}{274^\circ + t} \quad \therefore \quad H = \frac{(Q+q)\,(t'-t)}{274^\circ + t}$

Now, if the transferring medium parts with the quantity of heat q at the temperature $= t'$, and then is permitted to expand to its primary condition, and is made to give back by its expansion, the force of expansion, which is applied to the retrograding piston of the air or vapor pump, it will, when it reaches the first temperture $= t$, have given out force represented in heat units by $H' = \frac{Q + (t'-t)}{274^\circ + t}$ and the difference between the number of heat units expended in compression and those developed by expansion $= H - H' = \frac{Q+q\,(t'-t)}{274^\circ + t} - \frac{Q(t'-t)}{274^\circ + t}$ $= q\frac{(t'-t)}{274^\circ + t'}$, representing the units expended in the cycle of work.

Whatever mechanical effort may have been expended in the act of transfer of heat from the water to the medium, during the congelation in its certain time, will be compensated for, in the transfer which occurs from the medium to the water for removal of heat, at the higher point of temperature. The same quantity of heat $= q$ having to be taken up and given out in constantly recurring intervals of time—practically in the same times.

Multiplying the heat units by the mechanical equivalent $= J$, we have Pictet's formula: $q\frac{t'-t}{274^\circ + t}J =$ mechanical effort.]

Suppose we would make 100 kilos. of ice per hour with water of 20°. Each kilo. of ice in such case will represent $79+20=99$ calories. In order to estimate the force in horse-power, replace the letters by the following figures:

First, on the supposition of complete and instantaneous transfer of heat $t = 0^\circ$ temperature of congelation.

$t' = 20^\circ$ temperature of water of supply both for congelation, and for removal of surplus heat.

$J = 431$ kilogram-metres $=$ mechanical equivalent of heat.

One horse-power $= 270{,}000$ kilogram-metres per hour.

$$\therefore \quad 100 \times 99 \times \frac{20^\circ - 0^\circ}{274^\circ + 0^\circ} \times 431 \div 270{,}000 = 1{\cdot}154 \text{ horse-power.}$$

Second, for the machine with sulphurous acid there must be 10° difference of temperature at both extremes of the process between the water used, for congelation on the one hand, or for removal of excess of heat on the other, when

$t = -10°$ temperature transferring medium when vaporizing.
$t° + 10° = t' = 30°$ " " " to be condensed.
other values being as before (when $t°$ = temperature of water = 20°).

$$\therefore \quad 100 \times 99 \times \frac{30° - (-10°)}{274° + (-10°)} \times 431 \div 270{,}000 = 2{\cdot}4 \text{ horse-power.}$$

With the water at 10° $\therefore t = -10°$; $t' = 20°$, and each kilo. of ice representing 79 + 10 = 89 calories.

$$\therefore \quad 100 \times 89 \times \frac{20° - (-10°)}{274° + (-10°)} \times 431 \div 270{,}000 = 1{\cdot}618 \text{ horse-power.}$$

[The following table gives several numerical values to be applied in the formation of a scale which will exhibit graphically all the results from the formula:

TABLE OF COMPUTATION OF THEORETIC FORCE, in horse-power, demanded in making ice from water of various temperatures, on the supposition that the transfer medium be brought to 10° below the point of congelation for its lower temperature, and be carried to 10° above the water for removal of heat for its higher temperature, in order to effect the operation in a given time and against losses of heat.

Degrees Fahr.	Temperature of the water. $= t°$	Latent & sensible heat to be removed. $= 79° + t°$	Range of temperature to effect removal. $= t' + 10° = t° + 20°$	Absolute heat removed. $= \frac{t' + 10°}{264°}$	Theor'c horse-power demanded for 100 kilos. per hour. $= x$	Computed horse-power. $= x + 20$ per ct. x.
	Degrees.	Degrees.	Degrees.			
14	—10	69	10	0·0379	0·418	0·502
23	— 5	74	15	0·0568	0·672	0·806
32	0	79	20	0·0758	0·958	1·150
41	5	84	25	0·0947	1·273	1·528
50	10	89	30	0·1136	1·618	1·942
59	15	94	35	0·1325	1·993	2·392
68	20	99	40	0·1515	2·400	2·880
77	25	104	45	0·1704	2·835	3·402
86	30	109	50	0·1894	3·303	3·961
95	35	114	55	0·2083	3·800	4·560
104	40	119	60	0·2273	4·328	5·194

$$\text{Formula: } x = (L+t^\circ)\frac{\dfrac{q\,(t'-t)}{274^\circ+t}\times J}{270{,}000}$$

where L = latent heat of congelation = 79°; q = quantity of ice per hour = 100 kilos; t° = temperature of water, variable; $t = 10^\circ$ below point of freezing = —10°; $t' = t^\circ + 10^\circ$, variable; J = equivalent of heat = 431 calories.

$$\therefore\quad x = (79^\circ + t')\times\left(\frac{t'-(-10^\circ)}{264^\circ}\right)\times\left(\frac{100\times431}{270{,}000}\right)$$
$$= 0{\cdot}16\times(79+t')\times\left(\frac{t'+10}{264}\right)$$

Referring to the plate accompanying this paper, the line A represents the theoretic results of a machine using sulphurous acid. The abscissæ are the temperatures and the ordinates the corresponding forces in horse-power.]

3d. These results can be compared with the performance of the ice machine in the present Exhibition at Paris, the dimensions of which are as follows:

Stroke of piston or steam cylinder = 1 metre.
Diameter of " " = 50 centimetres.
Pressure of steam = 5 kilos.* per sq. centimetre.

Point of cut off of steam in cylinder = 10 centimetres.

Back pressure in steam cylinder = 0.15 kilos. per sq. centimetre.

Stroke of piston in cylinder for compression of sulphurous acid = 1 metre.

Diameter of cylinder for compression of sulphurous acid = 42 centimetres.

P = pressure at the time of expiration, 0·8 kilos. per sq. centimetre.
P' = " " compression, 2·7 kilos. "

Velocity, 30 to 32 turns per minute.

In "Claudel's formulas," will be found (¶s 356—372, of Ed. 1857), for calculating the dimensions of condensing steam engines having a single cylinder with cut off, the formula for estimating the power given out is:

---

*A kilogramme to the square centimetre = 14·22 lbs. to the square inch. An atmosphere = 14·7 lbs. per square inch, or 1·033 kilos per square centimetre. The horse-power, metrical value = 75 kilogram-metres per second = 270,000 kilogram-metres per hour = 1,052,971 lbs., in place of 1,980,000 lbs., the English value.

$$T_m = Vhk(1+\log.\left(\frac{z}{z_0}\right)\times 2{\cdot}3026 - \frac{h'}{h} + \frac{z}{z_0})$$

In this formula T_m = power given out in great dynamic units = 1,000 kilogram-metres—substituting for these their value in horse-power per second, we have

$$0{\cdot}075\, x = Vhk\,(1+\log.\left(\frac{z}{z_0}\right)\times 2{\cdot}3026 - \frac{h'}{h}\times\frac{z}{z_0})$$

which is the formula used in the original of this translation.

Where x = power given out in horse-power,

V = volume of steam per second of time, before cutting off, that is used under the full pressure h,

h = pressure of steam in metres of height of water = kilos. per sq. centimetre,

h' = back pressure in cylinder,

z = whole length of stroke in metres,

z_0 = length of stroke to point of cut off in metres,

Vh = labor done before cutting off,

$Vh\ \log.\left(\frac{z}{z_0}\right)\times 2{\cdot}3026$=labor done after cutting off.

k = co-efficient dependent upon resistance of engine, taken by M. Pictet at 0·73.*

substituting in the equations the values given, we have (taking the velocity at 30 turns per minute, or one stroke per second)—

$$0{\cdot}075\, x = \left[(0{\cdot}5^2)\times\frac{\pi}{4}\times 0{\cdot}1\times 5\times 0{\cdot}73\left(1+\log.\frac{1}{0{\cdot}1}\times 2{\cdot}3026 - \frac{0{\cdot}15}{5}\times\frac{1}{0{\cdot}1}\right)\right]$$

$$0{\cdot}075\, x = [0{\cdot}196\times 5\times 0{\cdot}73(1+1\times 2{\cdot}3026 - 0{\cdot}03\times 10)]$$

$$0{\cdot}075\, x = 0{\cdot}7154(3{\cdot}3026 - 0{\cdot}30) = 2{\cdot}14807$$

$$x = 2{\cdot}87 \text{ effective horse-power.}$$

---

*This value of 0·73 does not correspond to any value given by Claudel (edition 1857), where k has given many values, dependent on point of cut off, from 0·72 for ½d to 0.84 for ⅛th; and also other values dependent on the size of engine, thus for several sizes ef engines, all of which are supposed to cut off at one-fourth the stroke, the values given are from 0·44 for 4 to 6 horse-power to 0·74 for 60 to 100 horse-power. The co-efficient is purely empirical, and the value of the result in useful effect, derived from the computation, is not very satisfactory when it is considered that indicator cards could have been taken from the engine at the Exposition at any time.

[In the original, at this place there follows a computation of the force of compressing the gas in the compressing cylinder from 0·8 kilos. to 2·7 kilos pressure. It is impossible to accept this computation as the tension of vapor of sulphurous acid corresponding to 30°, the supposed maximum reached, or rather point of removal of heat, is 4·56 atmos. (= kilos. nearly), and the tension corresponding to 20°, the accepted temperature of the water, is 3·24 atmos. Probably the pressure P' was 3·7 kilos, but this value, used in the formula taken by M. Pictet & Co., gives a greater result in horse-power in the compression than was exerted in the steam cylinder. Indicator cards, with temperatures by observation, alone are reliable as practical data, and these are wanting to the above statements.]

The calculation of the weight of sulphurous acid evaporated at each stroke of the piston is as follows:

Density of sulphurous acid = 2·21

Weight per cubic litre, at 0°, = 2·88 grams.

$$\therefore \text{Weight} = W = \pi\, r^2 \times 1^{\text{m}} \times \frac{274}{274+t} \times 2{\cdot}88 \times 1000 \times 0{\cdot}8\,; \text{ taking } t = 0^{\circ}$$

$$W = 0{\cdot}1385 \times 2{\cdot}88 \times 1000 \times 0{\cdot}8 = 319 \text{ grams.}$$

The useful effect of the compression being 90 per cent. between the limits of pressure named, this weight is reduced to 287 grams per stroke or half revolution of the engine.

The latent heat of evaporation of sulphurous acid is 94·5 calories per kilogram vaporized. The weight of ice formed per hour, independent of external losses by radiation or conduction, is:

$$\frac{287 \times 60 \times 60 \times 94{\cdot}5}{99} = 1{,}000 \text{ kilograms [977 exact result.]}$$

This machine makes 1,000 kilos of ice per hour, and employs 29 horse-power, of which only 22 is utilized in the labor of compressing the vapor of the sulphurous acid.

4th. In the plate, the curve C shows the maximum tension of the vapor of sulphurous acid at the temperature given by the abcissa, as ascertained by M. Regnault. [In the original paper it reads, "The temperature corresponding to 2·7 kilos 'effective' is 25°." This allusion would confirm the view of the translator that the pressure obtained in the compressor cylinder is 3·7 kilos. at least, but this rendering is fatal to the computation of power in the compressor as it appears in the original.

5th. If the value of power expended which has been computed from the formula of Claudel on the data given by M. Pictet & Co. be accepted as giving a correct result in the one particular instance to

compare with that derived from the theory of heat, the simple addition of 20 per cent. to any of the theoretic values will exhibit with much fairness the practical useful effect. Some economies may attach to the performance of the larger apparatus, but those may be held to belong to the sizes of apparatus rather than to the resistance to be overcome. The line *B* shows the horse-power deemed requisite by M. Pictet & Co. to make 100 kilos of ice per hour. But the translator is of opinion that these values are about 25 per cent. too small, or, in other words, that the best practical result will be about 50 per cent. above the theoretic one, as there is not only to be met "the work expended in friction of connecting rods, cranks, pistons, screws, centrifugal pumps, etc.", but also many considerable and quite unavoidable losses of heat.]

6th. It is obvious that the same methods of reasoning and the same calculations will apply to higher or intermediate temperatures.

7th. [The final result from these considerations indicates a theoretic expenditure of force in making 100 kilos. of ice, per hour, by means of ice machines using sulphurous acid, to be from 1·27 to 4·3 horse-power, in countries having the extremes of temperature of 5° to 40°, and, according to M. Pictet & Co., from 1·53 to 5·2 horse-power, or, yet again, for liberal allowance, from 1·9 to 6·5 horse-power in countries having the same relations in temperature.

8th. Using a condensing engine, the consumption of coal per horse-power and per hour can easily be brought to 1·5 kilo. An engine cutting off its steam at 1-10th the stroke, as assumed in this case, with boilers of average economy, say the burning of 9 kilos of coal to the kilo. of water evaporated, = to the production of 4,833 calorics, should develop a horse-power with under one kilo of coal per hour. This assumption of a large value for the coal per horse-power is confirmatory to the expenditure of more power than was apparently given out by the computation. Taking the translator's estimate for horse-power demanded, and the assumption of engines and boilers with one kilo. of coal per horse-power per hour, we have, in countries where or when water at 5° is attainable, about 50 kilos. of ice to 1 kilo. of coal, while in the hottest supposable locality, where the water reaches 40°, 16 kilos. of ice can be made with 1 kilo. of coal burned. Accepting 30° as the temperature of water in a hot country, 100 kilos. of ice ought to proceed from the expenditure of 5 horse-power, and 20 kilos. of ice from the combustion of 1 kilo. of coal. The assumption of engines to cut off at one-tenth the stroke is, however, not generally admissible for any but the largest engines, and the allowance of 1·5 kilo. of coal per horse-power gives 13·3 kilos. of ice to each kilo. of coal burned, as a high practical result.]

9th. The use of water power will considerably reduce the cost of running an ice machine.

[It may be remarked, as a final result of the foregoing, that the economy of ice machines evidently depends, 1st, upon the small differences of temperature between the transfer medium above the cooling water, on the one hand, or below freezing point of water on the other. In the case where fluids are used which condense at temperatures and pressure within the range of the operation, it is possible that much heat may be given out to the cooling water above the point of condensation and a non-reversable cycle be set up; and the economy depends, 2d, on the economy of the source of motive power, that is, of the steam engine and boilers employed.]

Ice Machines using Ammonia.

10th. In considering this class of ice machines, it will be assumed that their construction and process in operation is known. The quantity of heat to be furnished to the boiler is composed of two entirely distinct parts, the first of which is that necessary to evaporate the ammonia in the freezer, utilizing the latent heat, while the second is the heat lost by escape of temperature through the transmission of the total amount of heat which has to traverse five heavy iron apparatus successively. This loss will be estimated at its maximum theoretic value.

11th. Taking for calculation the production of 100 kilos of ice between ordinary limits of temperature in warm countries, that is to say, condensation at +30° and freezing at −30°, we have for the first source of expenditure of heat the loss, between a temperature of +140° [corresponding to 16 atmospheres pressures] and −30°, which are the extremes of temperature between which the non-reversible cycle of operations is performed, = (taking the water at 20°)

$$9{,}900 \times \frac{140-(-30^\circ)}{274+(-30^\circ)} = 6900 \text{ calories.}$$

12th. And for second source of expenditure of heat—that of heat generated in the boiler, which is never returned, but is wasted in the process—we estimate the pressure in the boiler to be 16 atmospheres, which pressure shall be divided into:

4 atmospheres for steam,
12 " for the ammonia.

The distillations will occur proportionately to their maximum tensions, and then to remove 10,000 calories per hour [9,900, if the water

to be frozen is at 20°] there should be evaporated 10 kilos. of water and 31 kilos. of ammonia.

We have then to adjust these two quantities of heat in order to find the minimum amount to be furnished by the boiler. [The total heat of water vaporized at +140° = 656 calories.]

The total heat of ammonia at +140° is 465 calories.

But the temperature of ammoniacal liquor with which the boiler is fed is 90°, which will reduce these figures to

566 calories for the water,
and to 411 " for the ammonia.

10 kilos. of water, at 566° = 5,660
31 " of ammonia, at 411° = 12,740 to which is to be added the theoretic loss as before computed = 6,900

25,300

There should be furnished 25,300 calories to the boiler as the least quantity to produce 100 kilos. of ice.

14. * * * [Supposing the consumption of fuel under the boiler is effected with average economy, as previously assumed, of = 9 kilos of water evaporated (4,833 calories) per kilo. of coal burned, we have:

$\frac{25,300}{4,833}=5{\cdot}235$ kilos. of coal to the 100 lbs. of ice per hour, as the theoretic result without loss of heat in any way during the process. This result does not fairly represent the argument of M. Pictet & Co. The heat should be divided into two parts, as in the estimate. Of which 5,660 12,740=18,400 calories will proceed from application of heat of fuel to the boiler, when $\frac{18,400}{4,833}=3{\cdot}8$ kilos of coal may be assumed to supply this heat. And the 6,900 calories which will have been expended in transferring 9,900 calories through a range of 170°, by exertion of mechanical force, may be taken (having been derived through the action of a steam engine and pump) to have been effected as economically as was assumed in the sulphurous acid process. In the sulphurous acid process, with water at 20°, we have the heat of transferring the heat of congelation$=9,900\times\frac{30^\circ-(-10^\circ)}{274^\circ+(-10^\circ)}=1,500$ calories, and our previous estimate gives 2·4 horse-power as the theoretic force accompanying the same. When $\frac{6,900}{1,500}\,2{\cdot}4=11{\cdot}04$ horse-power, which may be taken at 1·5 kilo. of coal per horse-power, as before (¶ 8th).

The theoretic quantity of coal consumed by the ammonia process then becomes 3·8 + 16·75=20·37 kilos. (against the 3·6 kilos. by the sulphurous acid process.

14A. It is noted in the original that the above estimate does not include the power for driving the feed pump or for agitating the liquid, and there is estimated at least 1·5 kilos. for these purposes and for the force expended in the transmission, and reference is made to lines of theoretic and practical effect of ammonia ice-making machines which do not seem founded on any reliable data or experimental basis. This portion of the paper would be more satisfactorily presented if it had the authorization of the maker of the Carré machine.]

CURVES OF USEFUL EFFECT, ETC.

OF

ICE MACHINES USING SULPHUROUS ACIDS.

RAOUL PICTET, Paris.

Line A shows theoretic useful effect.

Line B shows probable practical force demanded with Condensing Engine cutting-off at 1-10th.

Line C shows maximum tension of vapor of sulphurous acid, according to Regnault.

BRIGGS.